Future Prediction of Eastern North American and Western Atlantic Extratropical Cyclones in the CMIP5 Models During the Cool Season

Brian A. Colle, Zhenhai Zhang, Ping Liu, Kelly Lombardo, Edmund Chang, and Minghua Zhang,
Stony Brook University - SUNY

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Motivation

- Determine how well the CMIP5 models can simulate the western Atlantic and eastern North American extratropical cyclones (density, intensity, genesis, deepening, etc…) for the cool season (Nov-March) for 1979-2004 historical period.
- Is there any indication of future cyclone change during the cool season? Frequency, intensity, or spatial distribution?
- What are some possible reasons for these changes?
- How will precipitation amounts change over the Northeast U.S. during the cool season?

Data and Methods

- **CFSR**: Climate Forecast System Reanalysis from NCEP, 1979-2004, 6-hourly (Also tried ERA-Interim)
- **CMIP5**: 15 models from the Coupled Model Intercomparison Project Phase 5.

  Historical – 1979-2004, 6-hourly

  Rcp8.5 - high emissions scenario, 2006-2098, 6-hourly

- **NARCCAP**: North American Regional Climate Change Assessment Program (~50 km grid spacing).

CMIP5 Models Verified (Higher Resolution in Bold)

Model	Center	Atmos. Horiz. Resolution (lon. x lat.)	Number of model levels	Reference
CCSM4	**National Center for Atmospheric Research, USA**	**1.25 x 0.94**	**26**	**Gent et al. (2011)**
EC-Earth	**EC-Earth Consortium**	**1.125x1.12**	**62**	**Hazeleger et al. (2010)**
MRI-CGCM3	**Meteorological Research Institute, Japan**	**1.125 x 1.12**	**48**	**Yukimoto et al. (2011)**
CNRM-CM5.1	**National Centre for Meteorological Research, France**	**1.4 x 1.4**	**31**	**Michou et al. (2011)**
MIROC5	**Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan**	**1.4 x 1.4**	**40**	**Watanabe et al. (2010)**
HADGEM2-ES	**Met Office Hadley Centre, UK**	**1.875 x 1.25**	**38**	**Jones et al. (2011)**
HADGEM 2-CC	**Met Office Hadley Centre, UK (Chemistry-coupled version)**	**1.875 x 1.25**	**60**	**Jones et al. (2011)**
INMCM4	Institute for Numerical Mathematics, Russia	2.0 x 1.5	21	Volodin et al. (2010)
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	2.50 x 1.25	39	Dufresne et al. (2012)
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	1.9 x 1.9	47	Jungclaus et al. (2006); Zanchettin et al. (2011)
NorESM1-M	Norwegian Climate Center, Norway	2.5 x 1.9	26	Zhang et al. (2012)
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 x 2.0	24	Donner et al. (2011)
IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	3.75 x 1.8	39	Dufresne et al. (2012)
BCC-CSM1.1	Beijing Climate Center, China Meteorological Administration, China	2.8 x 2.8	26	Wu et al. (2011)

Cyclone Tracking: 6-h SLP Data Using Hodges (1994;1995) TRACK Approach (see my MAPP presentation 2011/11).

Main Parameters:

- Wavelength (600 – 10000km)

→removing the planetary scales and too small scales

- Minimum Lifetime (24 hours)
- Minimum moving distance (1000km)

→filtering centers exist for too short time or remain too stationary

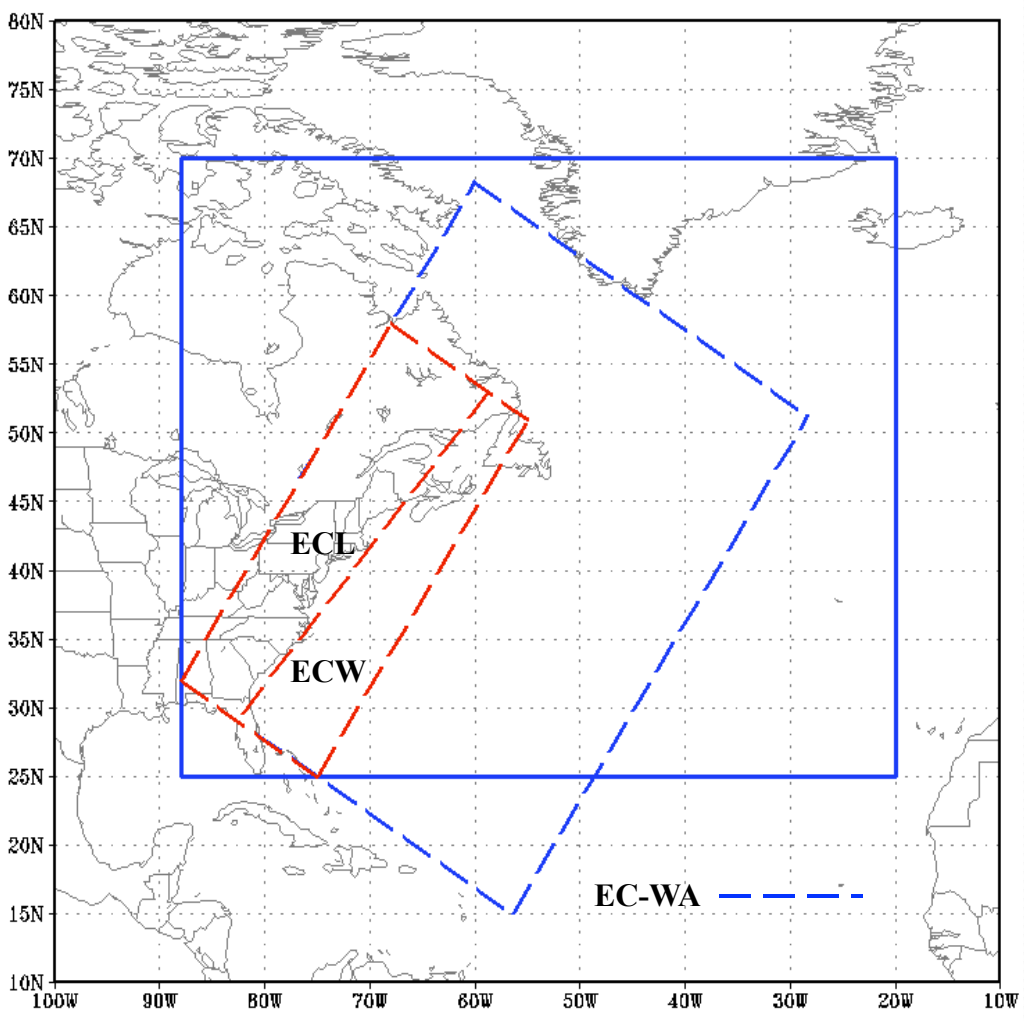
- Also compared with the Hodges 850 hPa Vorticity Tracking →Identified too many non-cyclones.

Regions and Time Periods

Cool Season
November – March, 5 months

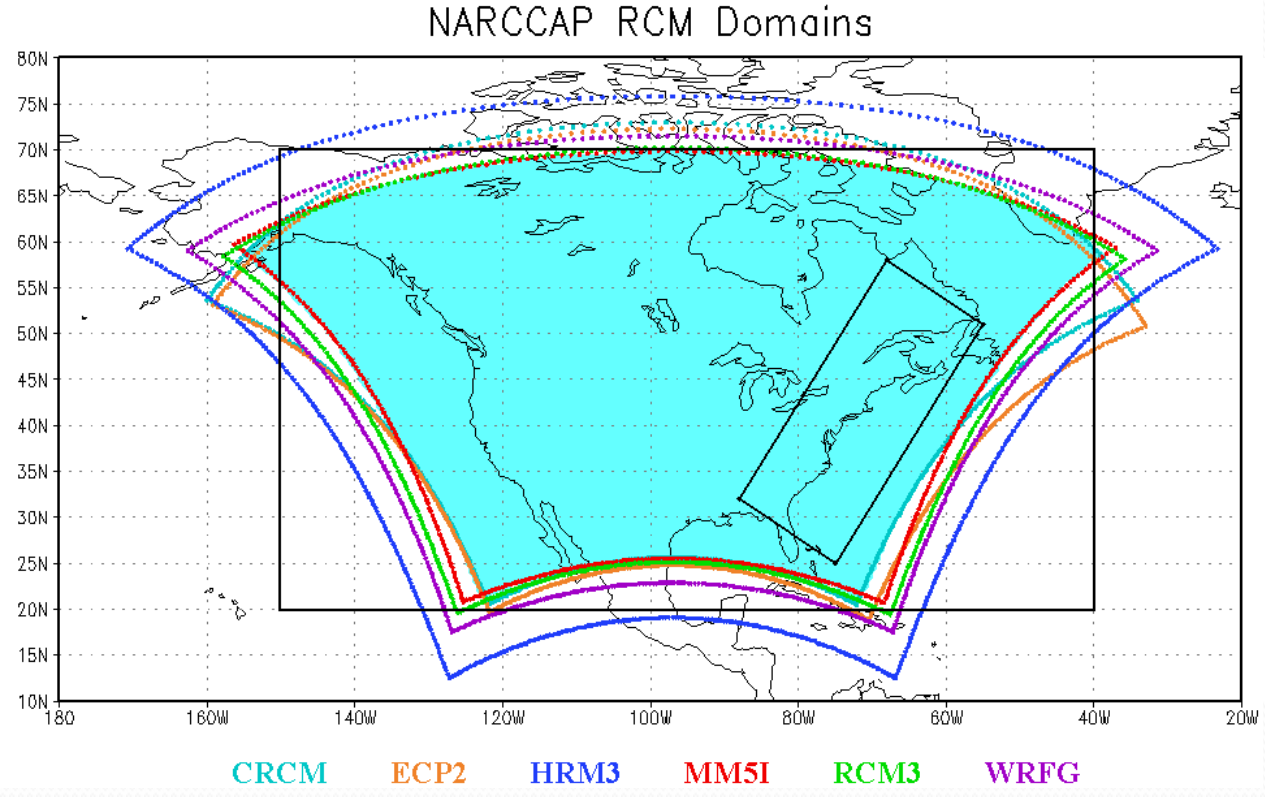
Historical part
1979 – 2004 (26 cool seasons)

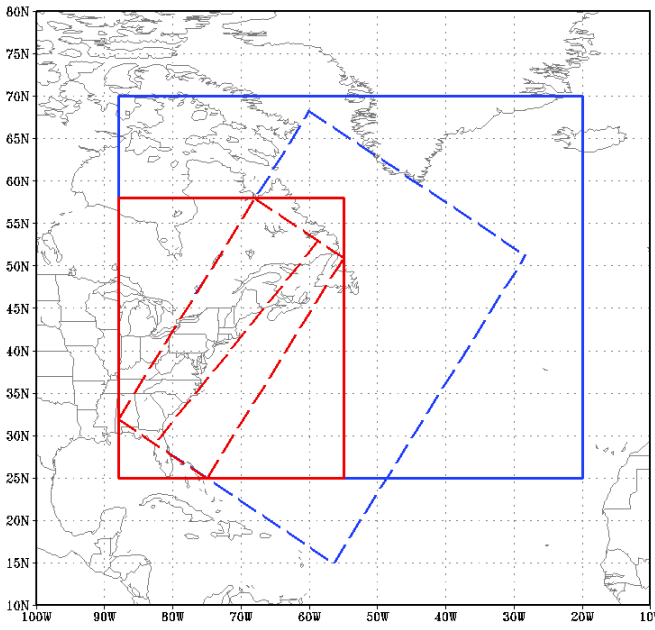
3 Future parts
Early 21st Century 2009-2038
Middle 21st Century 2039-2068
Late 21st Century 2069-2098



NARCCAP: North American Regional Climate Change Assessment Program (50 km grid spacing)

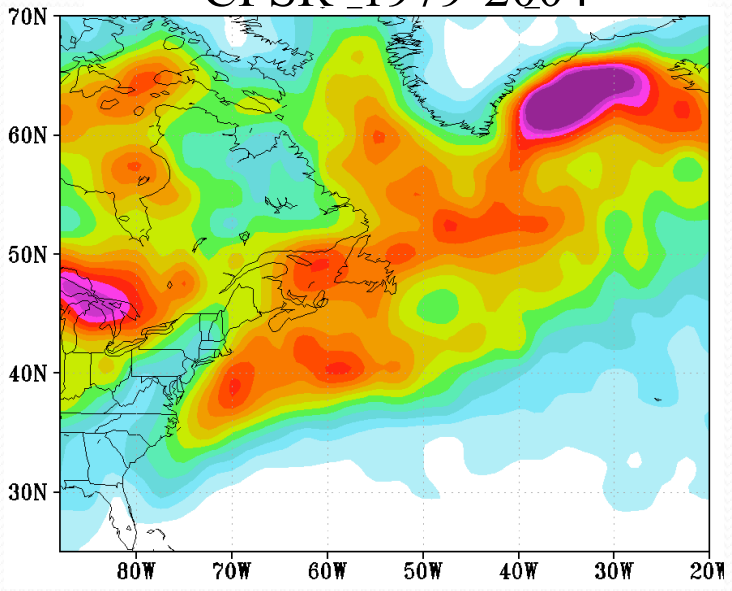
	NCEP	CCSM	CGCM3	HADCM3	GFDL
CRCM	1979-1998	1979-1998 2039-2068	1979-1998 2039-2068		
WRFG	1979-1998	1979-1998 2039-2068			
RCM3	1979-1998				1979-1998 2039-2068
HRM3	1979-1998			1979-1998 2039-2068	
MM5I		1979-1998 2039-2068			

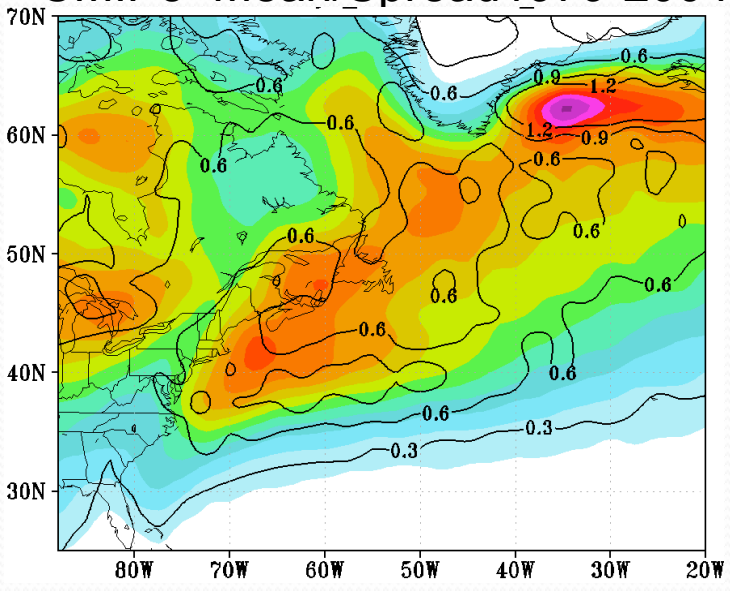


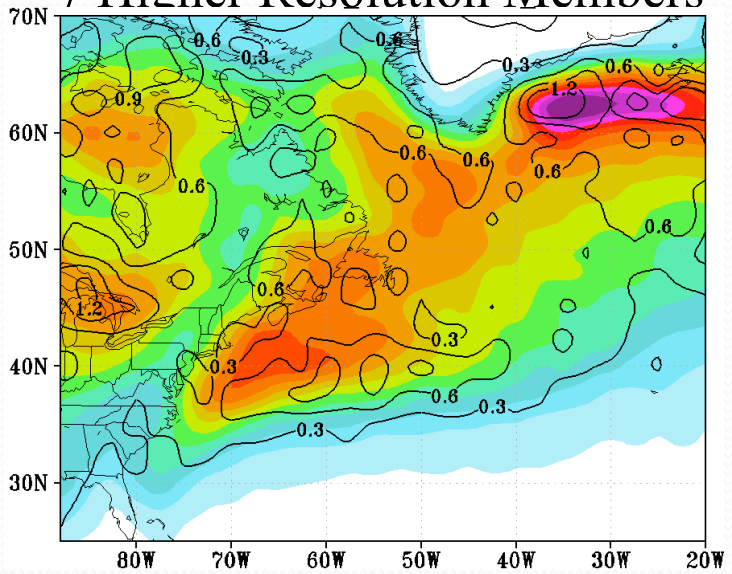


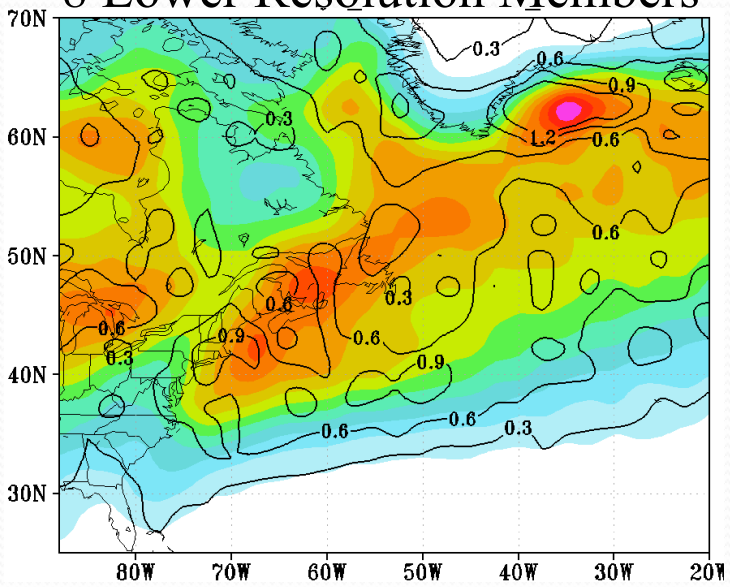
Cyclone numbers per cool season per 2.5° x 2.5°

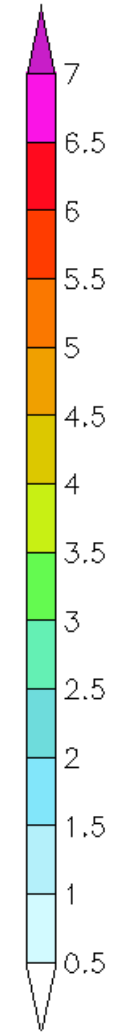
Cyclone Track Density







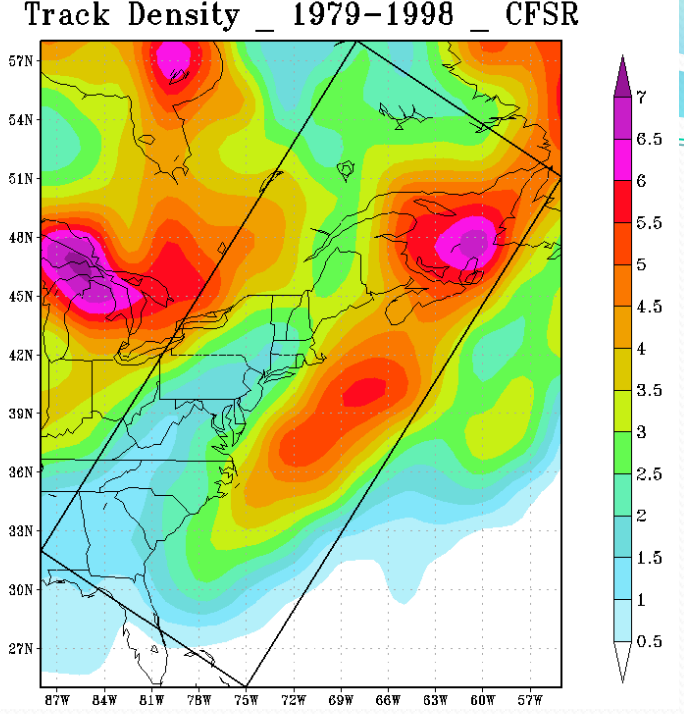


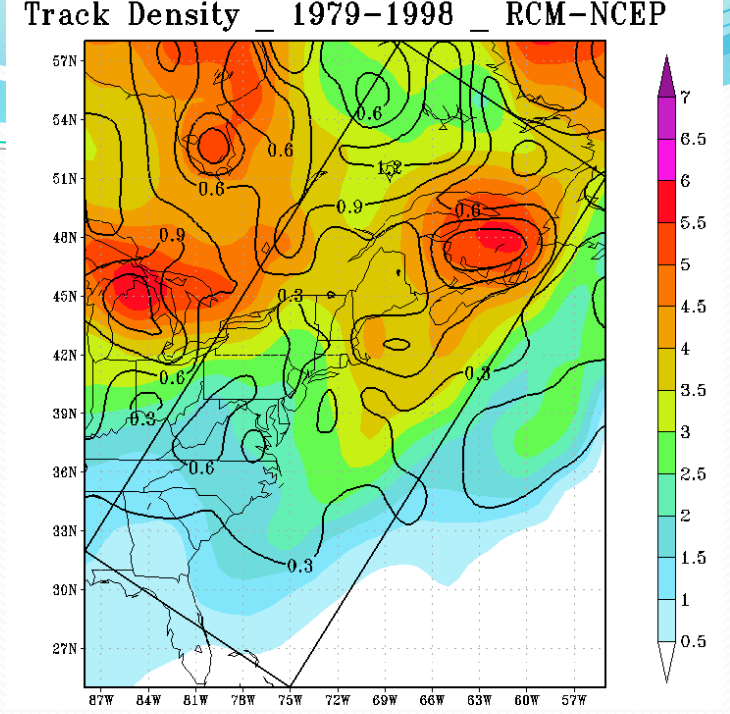


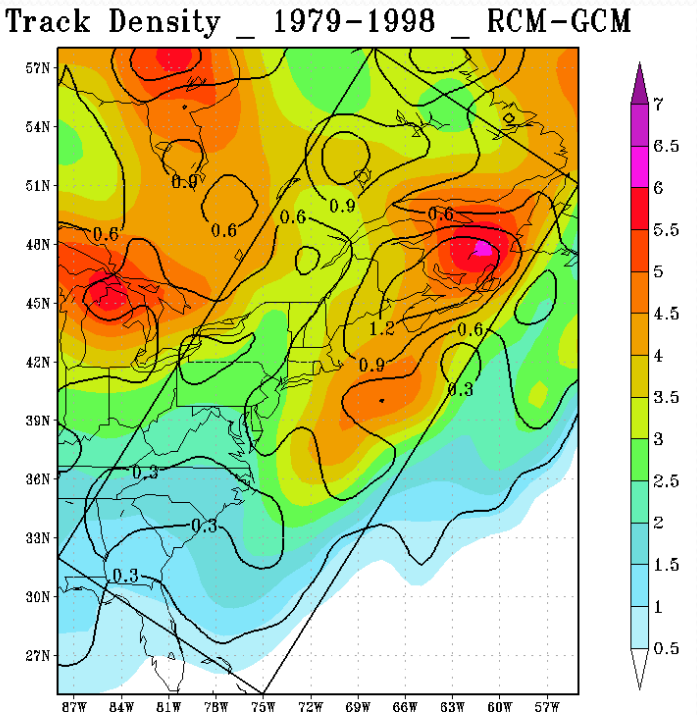
NARCCAP Track Density

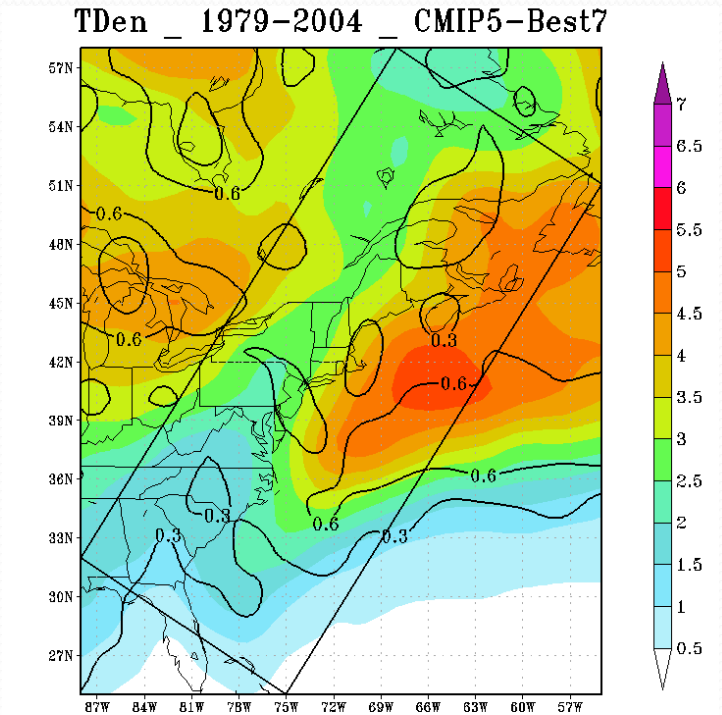
1979-1998/ 2004

(NARCCAP/CMIP5)

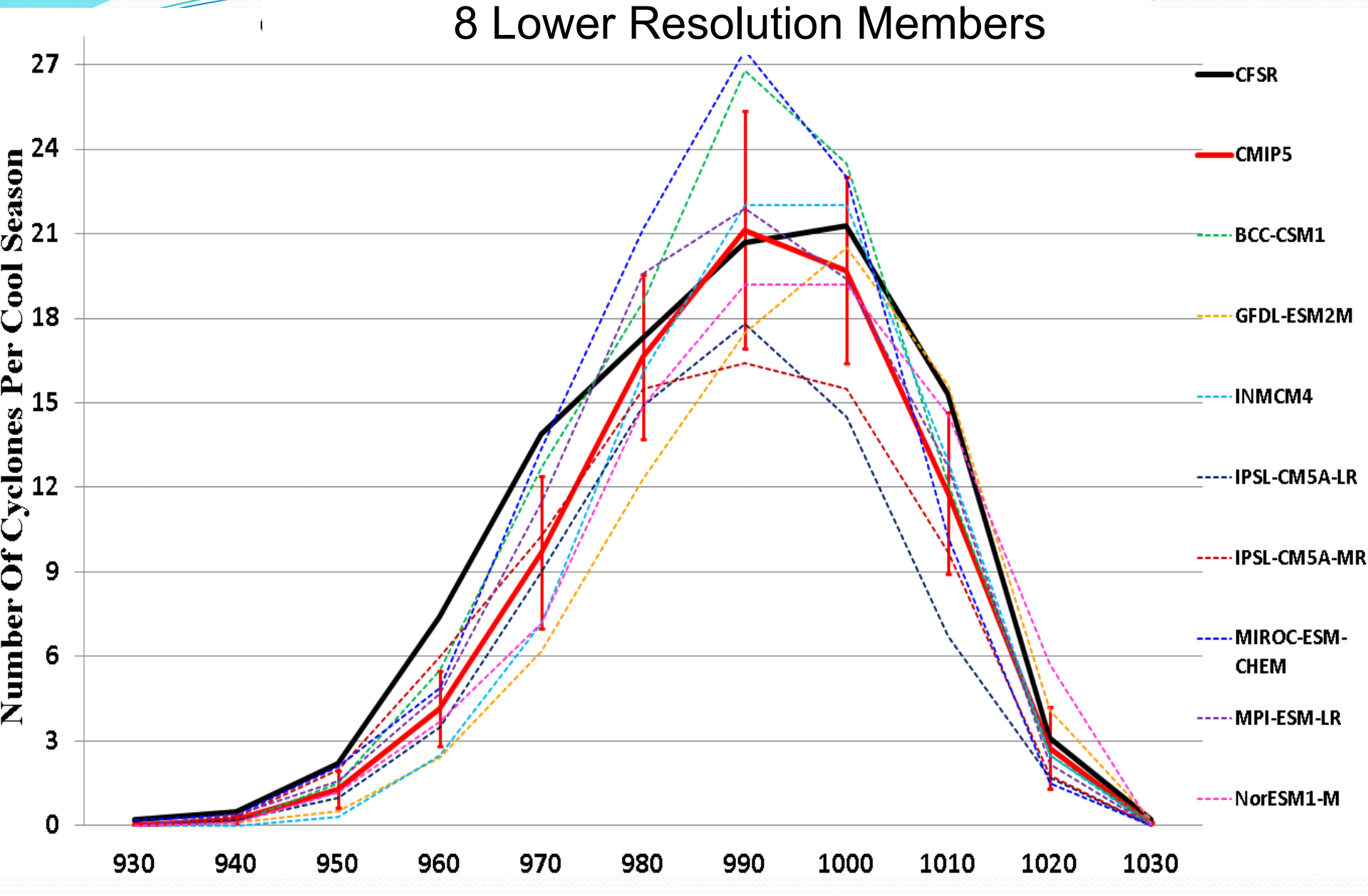




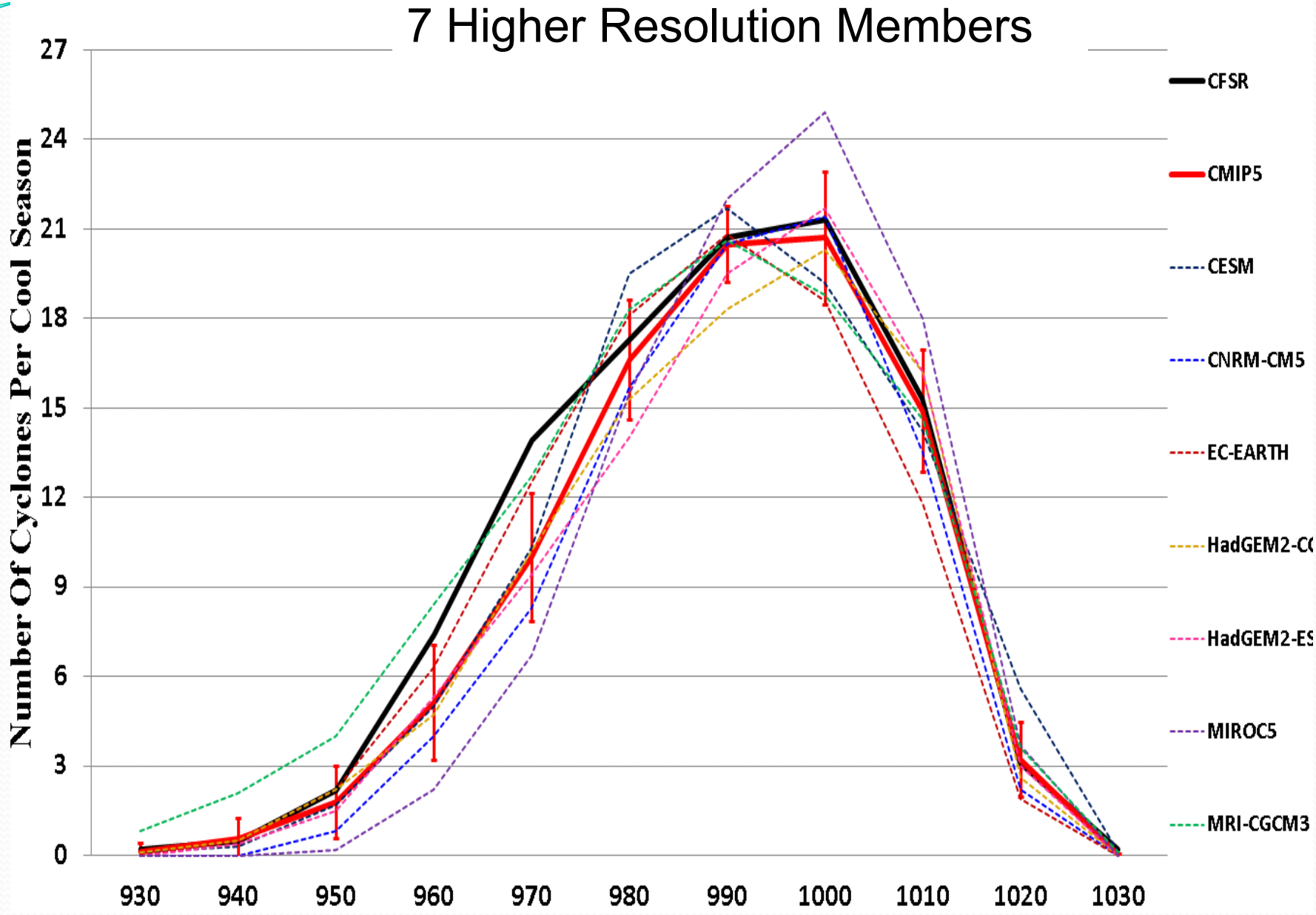




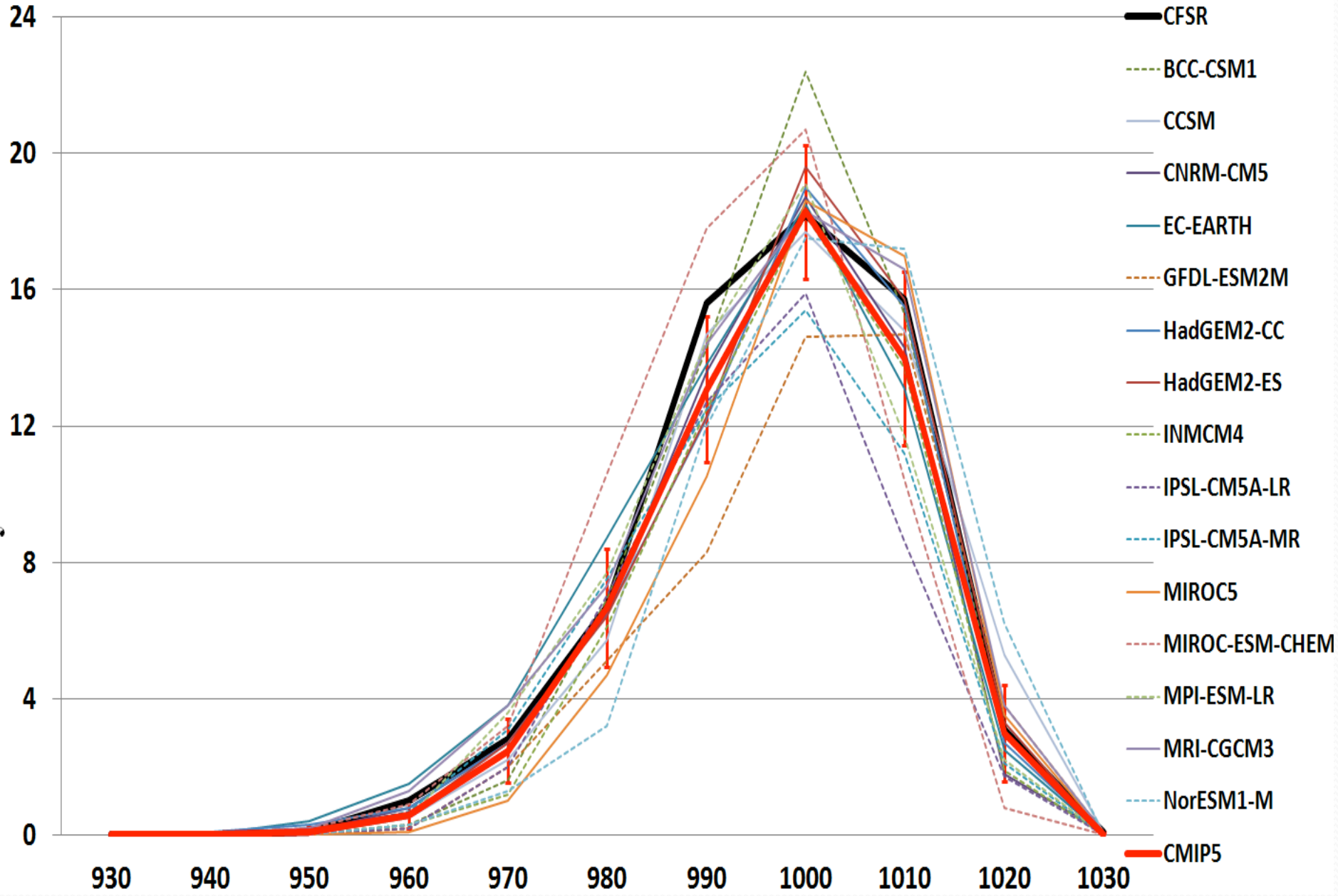
Cyclone Intensity Distribution (EC-WA region)



Cyclone Intensity Distribution (EC-WA region)



Cyclone Intensity Distribution _ East Coast



CMIP5 Cyclone Ranking (Rk)

Rank (**BOLD – high resolution**)

Models	TR	TD	PR	PD	*Rk-TR*	*Rk-TD*	*Rk-PR*	*Rk-PD*
EC-EARTH	***0.9493***	***0.532***	***0.9889***	***3.13***	***1***	***4***	***2***	***3***
MRI-CGCM3	***0.9091***	***0.517***	***0.9920***	***1.90***	***9***	***2***	***1***	***1***
CNRM-CM5	***0.9415***	***0.513***	***0.9797***	***5.23***	***2***	***1***	***7***	***7***
MPI-ESM-LR	0.9404	0.553	0.9831	3.77	3	6	5	4
HadGEM2-ES	***0.9284***	***0.519***	***0.9812***	***4.10***	***6***	***3***	***6***	***6***
HadGEM2-CC	***0.9108***	***0.555***	***0.9873***	***4.03***	***8***	***7***	***4***	***5***
CCSM4	***0.9180***	***0.651***	***0.9759***	***3.07***	***7***	***11***	***9***	***2***
IPSL-CM5A-MR	0.9325	0.708	0.9879	8.20	4	12	3	13
BCC-CSM1	0.9035	0.544	0.9764	5.97	12	5	8	8
INMCM4	0.9081	0.577	0.9631	6.07	11	8	10	9
GFDL-ESM2M	0.9307	0.588	0.9460	8.43	5	9	15	14
NorESM1	0.9089	0.747	0.9629	6.57	10	13	11	10
MIROC5	***0.8884***	***0.640***	***0.9469***	***7.10***	***14***	***10***	***14***	***11***
IROC-ESM-CHEM	0.8839	0.783	0.9609	7.50	15	14	12	12
IPSL-CM5A-LR	0.8987	0.879	0.9594	10.93	13	15	13	15
Mean	*0.9667*	*0.340*	*0.9868*	*3.67*				
Best7	*0.9634*	*0.352*	*0.9932*	*2.80*				
HRes7	*0.9614*	*0.358*	*0.9899*	*2.82*				
LRes8	*0.9580*	*0.379*	*0.9828*	*4.89*				

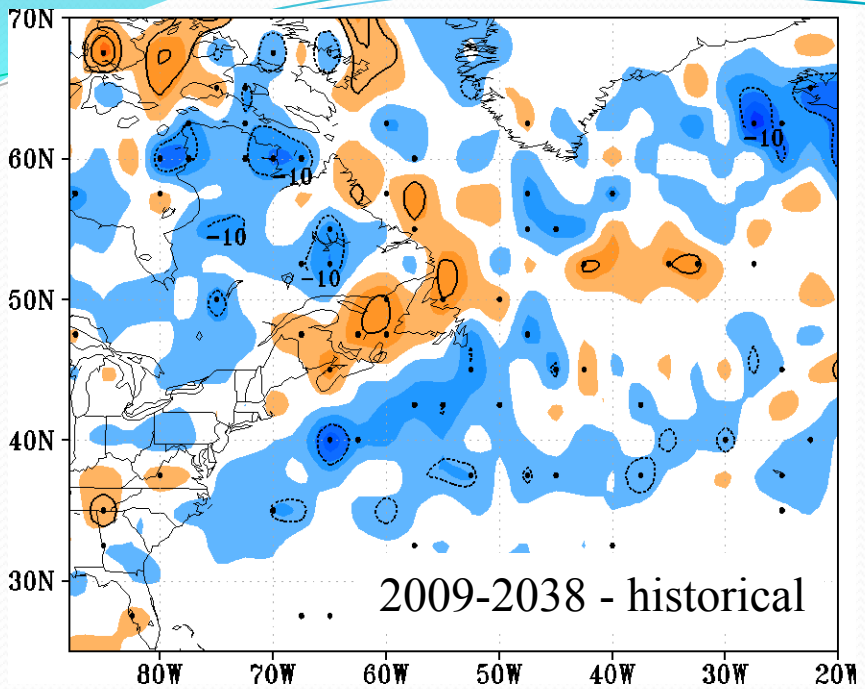
TR = Track density correlation

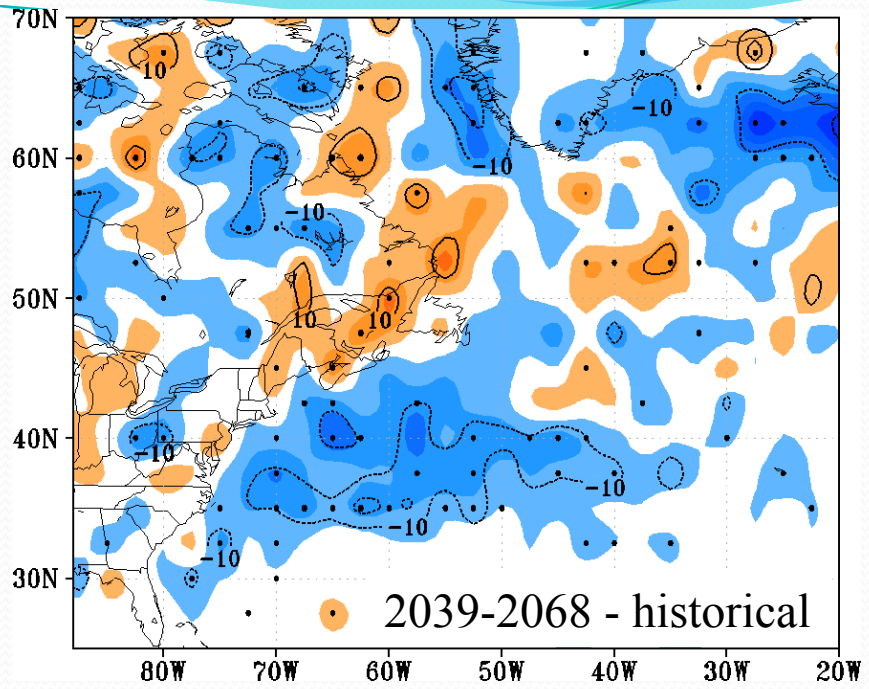
TD = Track density absolute error

PR = Central Pressure correlation

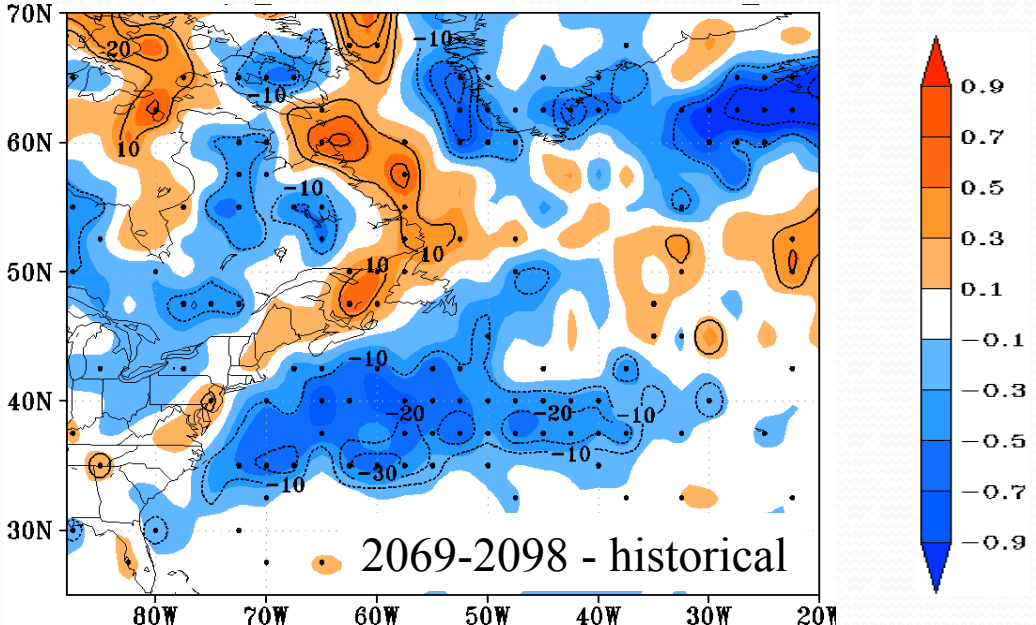
PD = Mean absolute difference of cyclone number in pressure bins

Future Cyclone Density Change "Best 7"





% Change is contoured. Dots are locations where 6 or the 7 Best7 models have the same sign for the future change

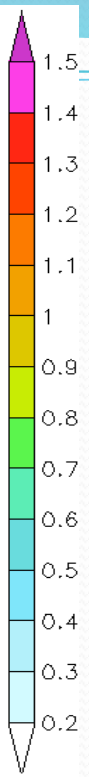


6-h Deepening Rates > 5 hPa

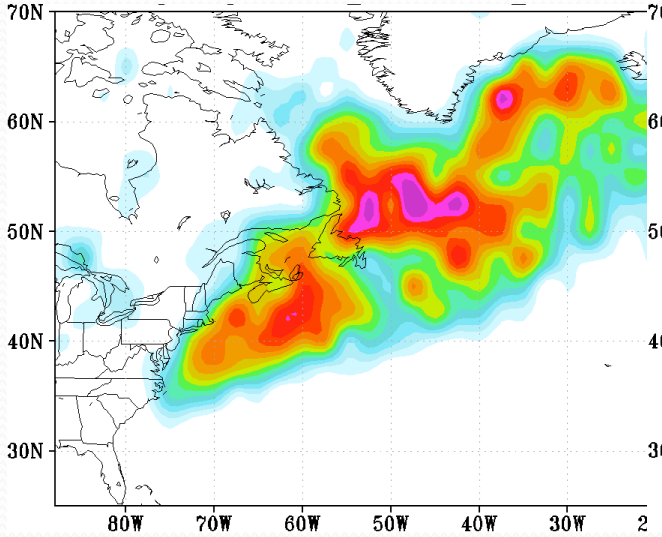
Cyclone numbers per 5 cool seasons per 2.5° x 2.5°

% change contoured

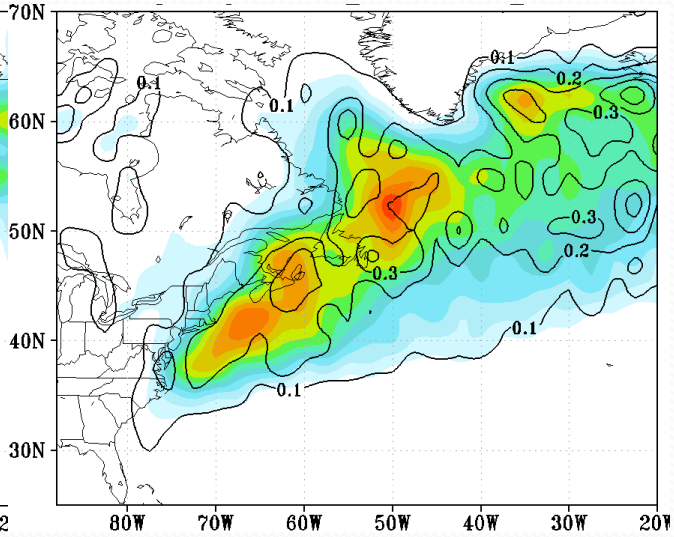
Best7 members



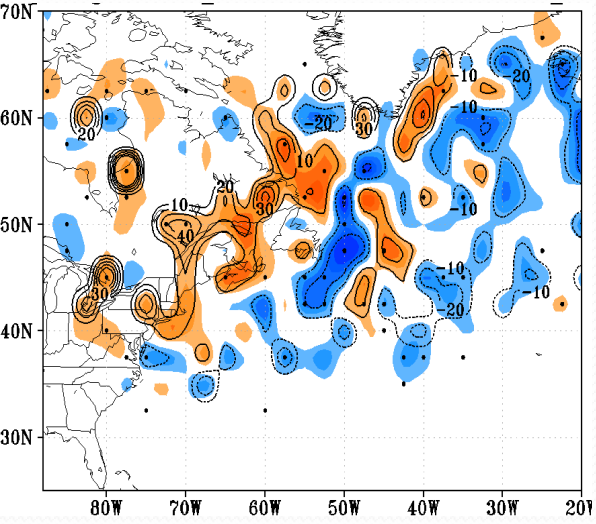
CFSR_1979-2004



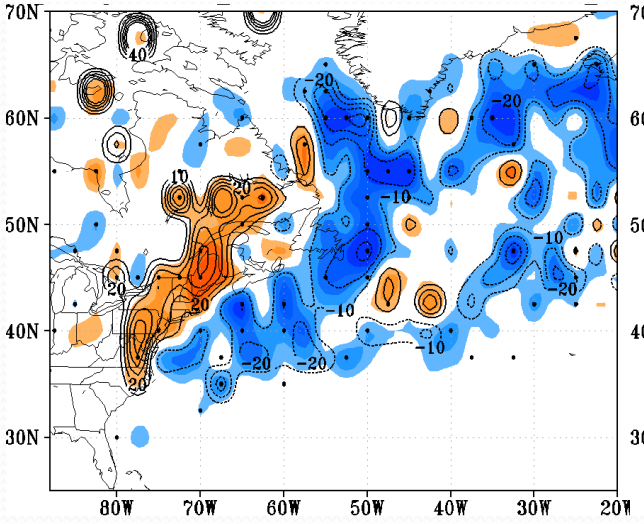
CMIP5_1979-2004



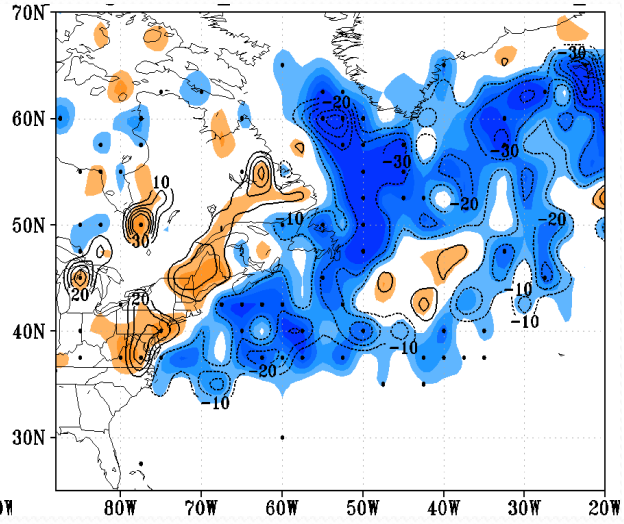
(2009-2038) - historical

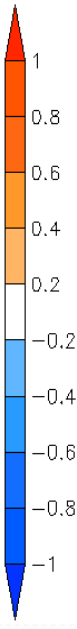


(2039-2068) - historical

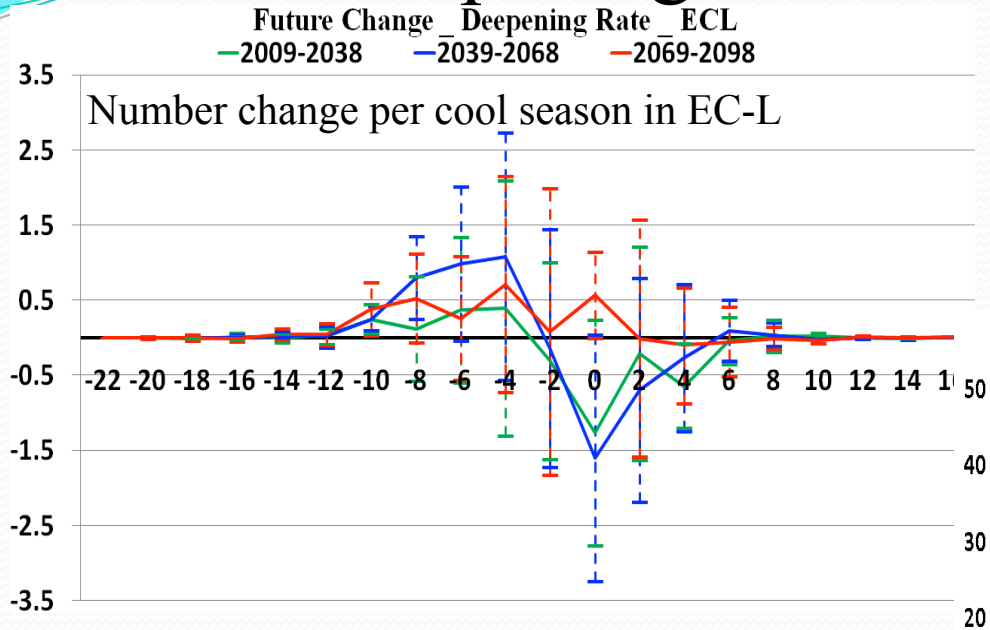


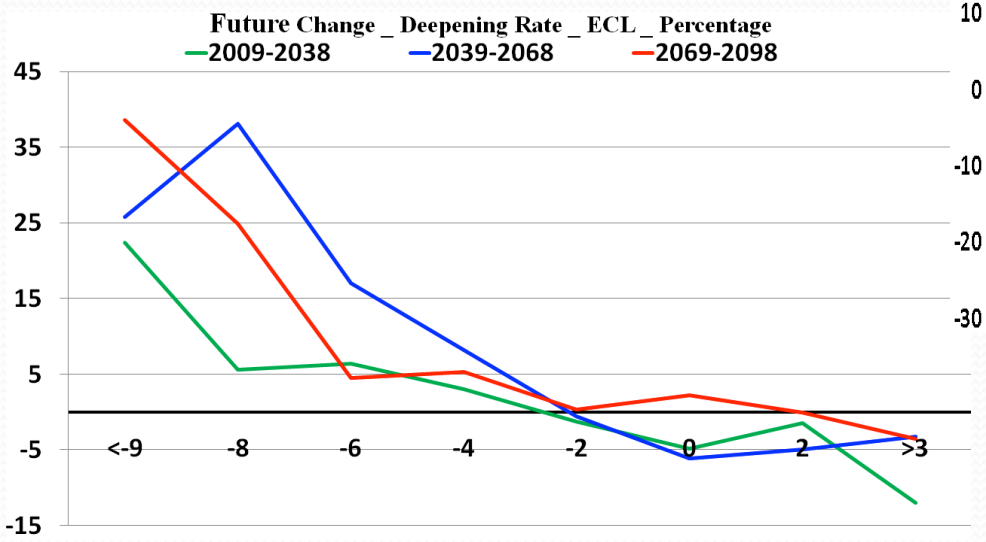
(2069-2098) - historical



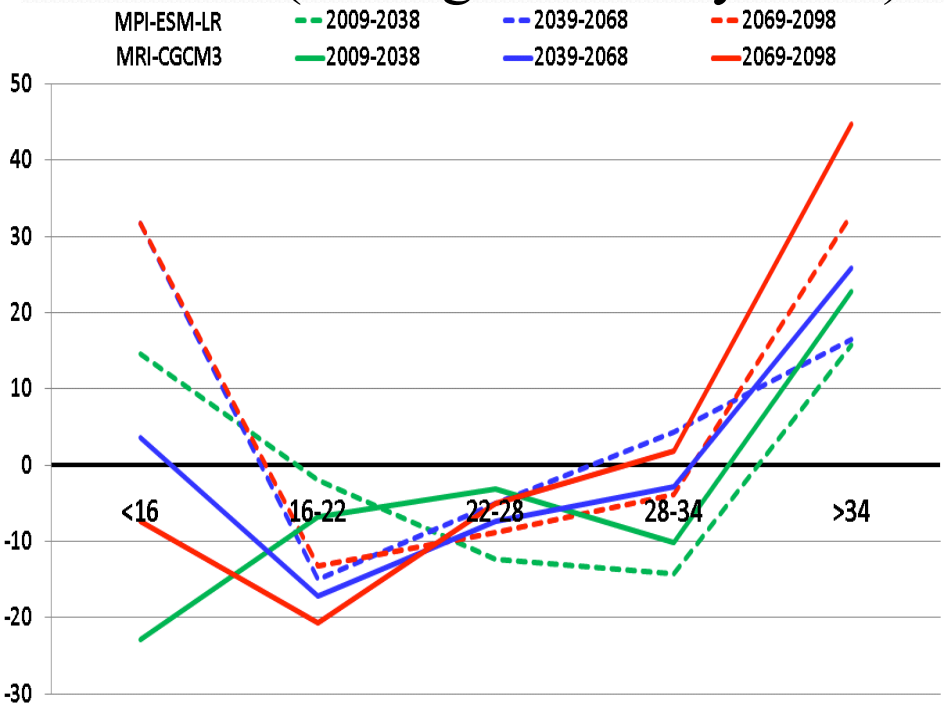


EC-L Region Future Change in 6-h Deepening Rates

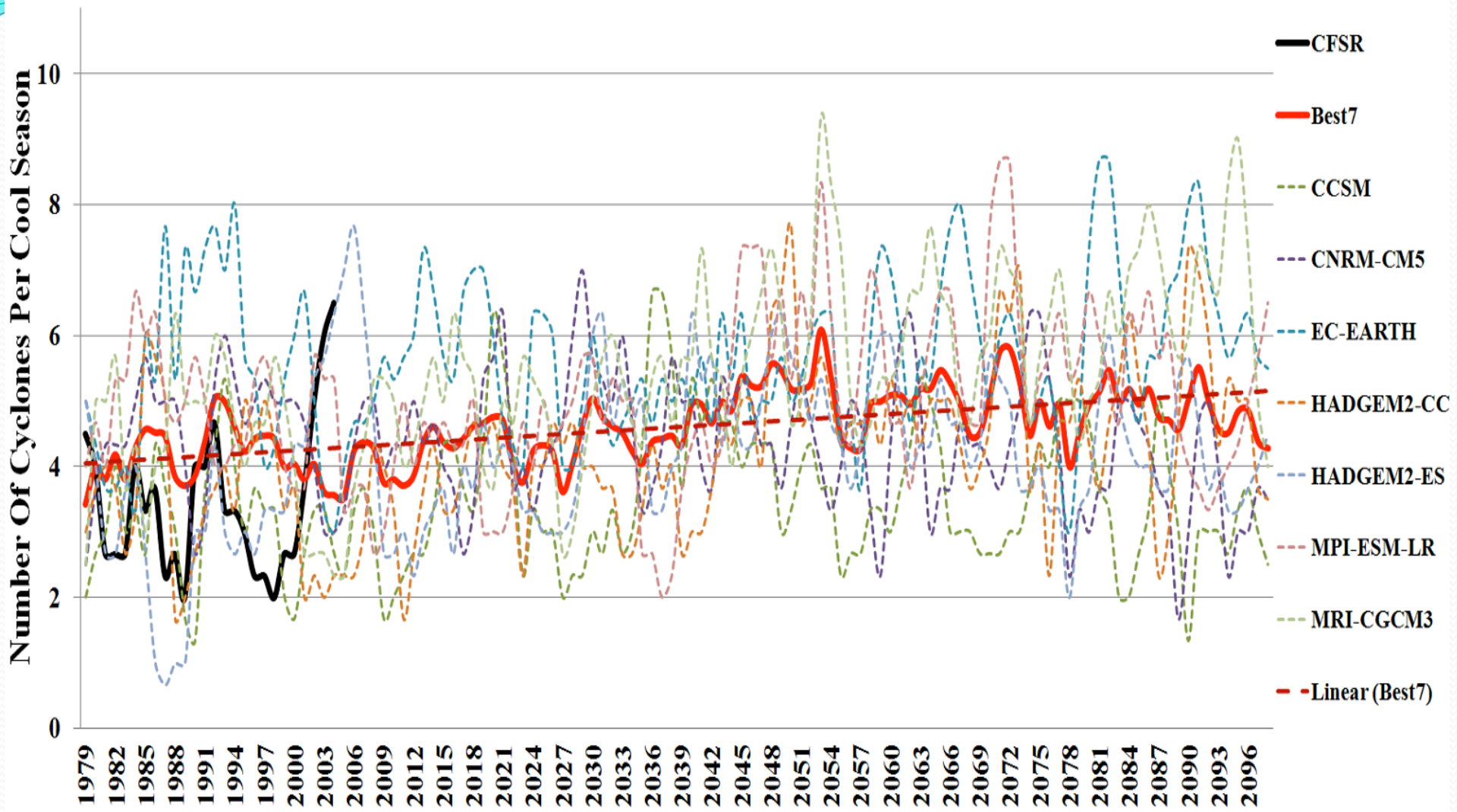




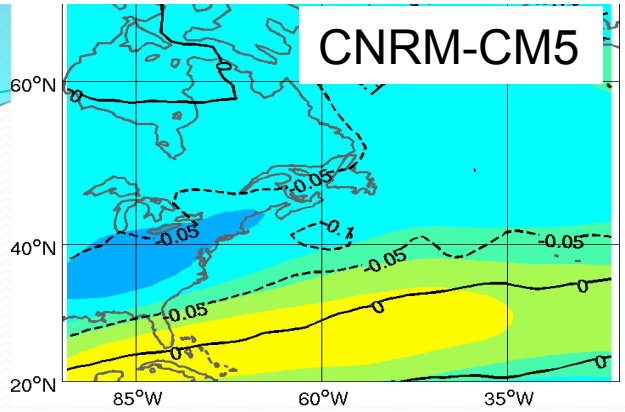
% Change in the number of 850 hPa wind bins for MPI and MRI models (10 deg around cyclone)



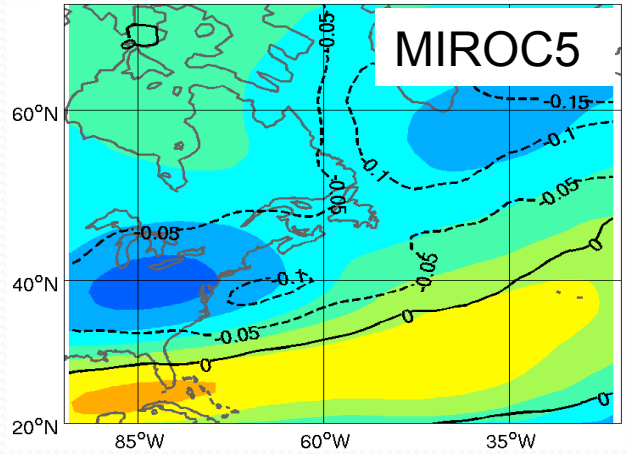
Number of Deep Cyclones (<980hPa) _ ECL _ 1979-2098

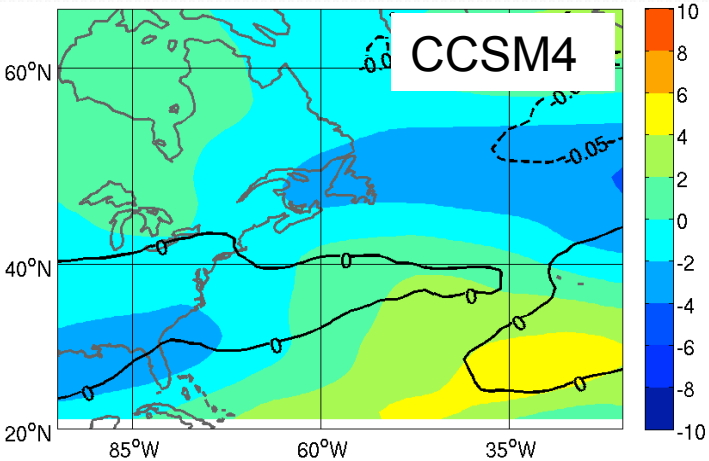


850-500 hPa Eady Growth Rate Change (contoured every 0.05 day^{-1}) and 250 hPa wind difference (shaded every 2 m s^{-1}) (2039-2068 minus historical)

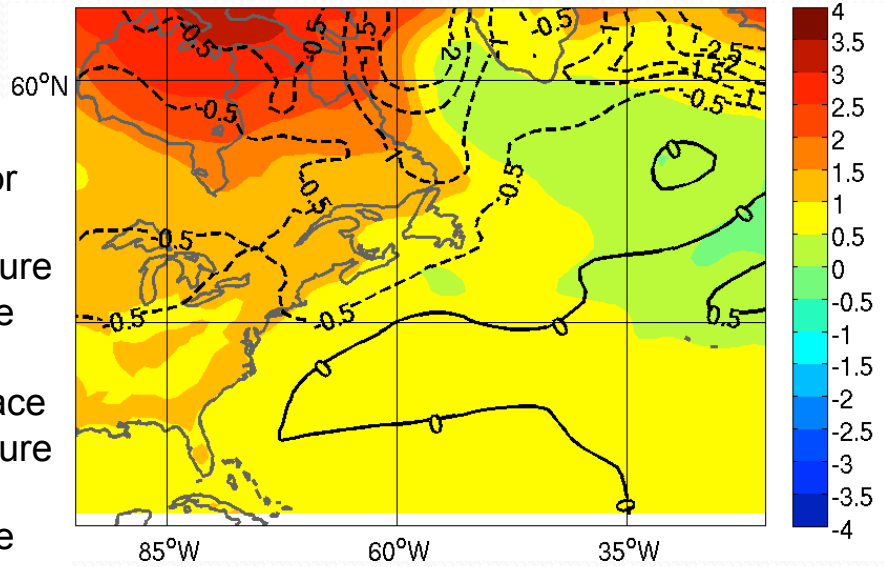


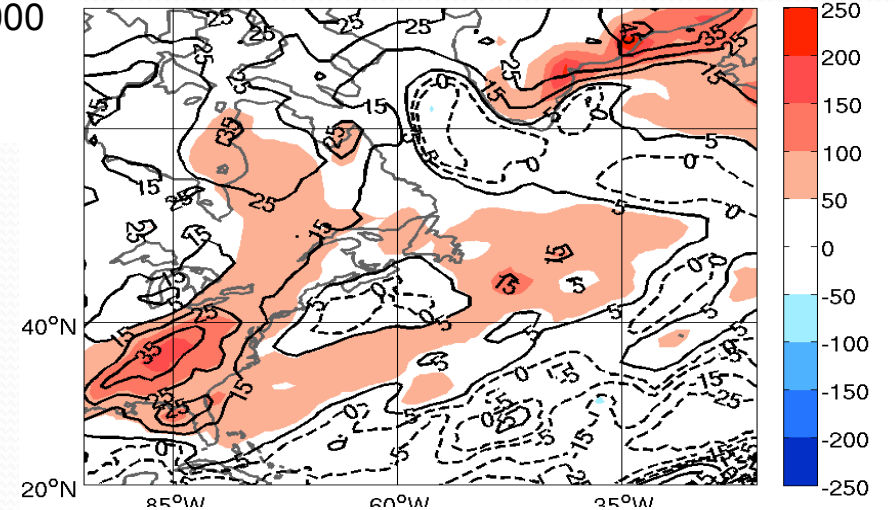
$$\sigma = 0.31 \frac{f}{N} \left| \frac{\partial V}{\partial z} \right|$$





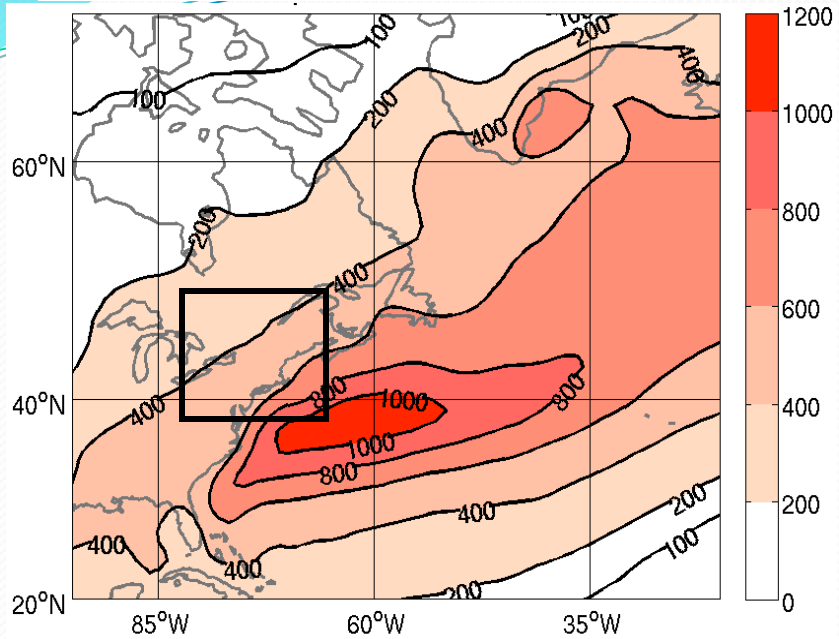
Same as left but for surface temperature difference (shaded) and surface temperature gradient difference (contoured degC/1000 km) for CCSM4



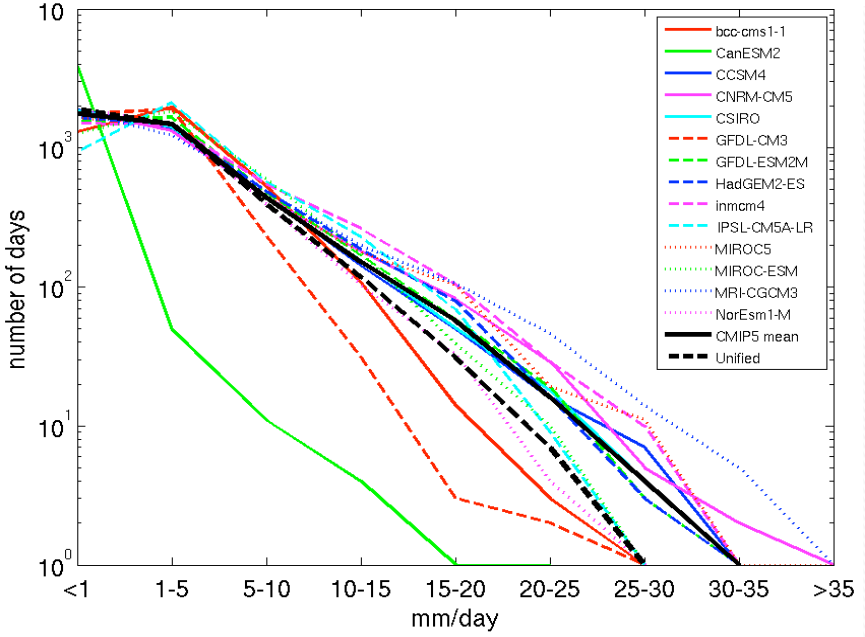


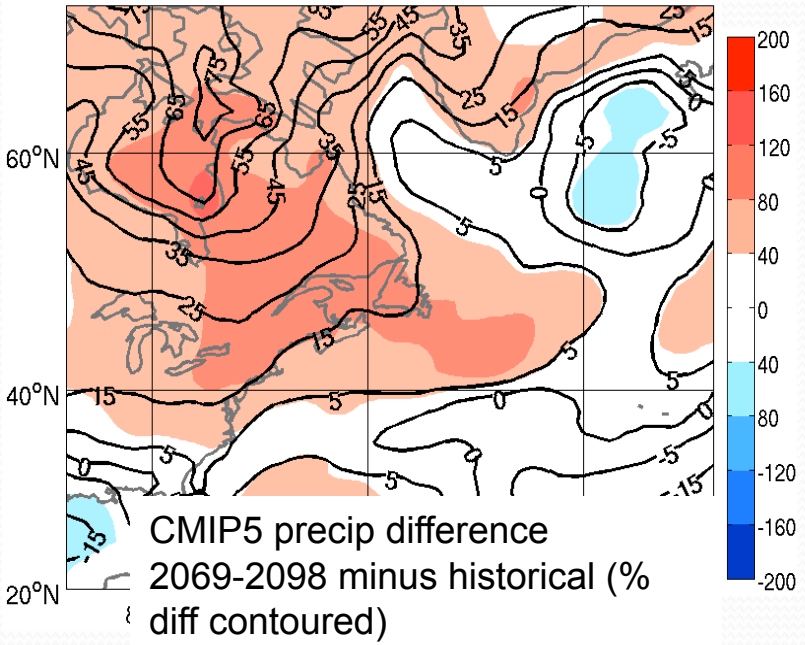
Same as left but for cool season precipitation difference (shaded in mm) and percent change (contoured) for CCSM4

CMIP5 Mean historical precip (mm per 5 cool season months



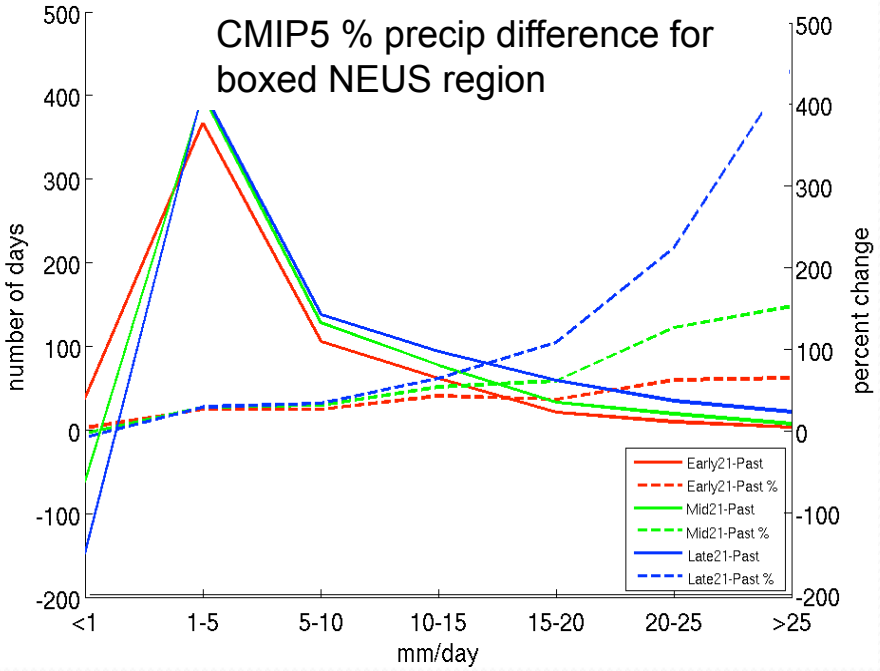
CMIP5 vs Unified (analysis over land) precipitation distribution for 1979-2004 for NEUS box region





CMIP5 precip difference 2069-2098 minus historical (% diff contoured)

CMIP5 % precip difference for boxed NEUS region



Summary

- The 15 CMIP5 models can realistically predict the 1979-2004 cyclone density distribution over the western Atlantic and U.S. East Coast during the cool season; however, most of the CMIP5 models underpredict the magnitude (underprediction even worse in the 50-km NARCCAP models).
- The higher resolution CMIP5 models better simulate the cyclone density and intensity, but most models underpredict the relatively deep cyclones (< 980 hPa).
- The cyclone numbers decrease gradually over western Atlantic for Rcp8.5 experiment, but there are more frequent rapid deepening storms just inland of East coast by mid-21st century, as well as more frequent heavy precipitation events.
- There is little Eady growth rate and increased temperature surface gradient change along U.S. East coast, but there is a relatively large precipitation increase, suggesting enhanced cyclone growth through diabatic heating (more work needed…).